Defense Technical Information Center
Compilation Part Notice

ADP010696

TITLE: Integrating Information from Multiple
Sources: Expert Decision Making Procedures

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Usability of Information in Battle
Management Operations [1'Exploitation de
l'information dans les operations de gestion du
champ de bataille]

To order the complete compilation report, use: ADA389629

The component part is provided here to allow users access to individually authored sections
of proceedings, annals, symposia, ect. However, the component should be considered within
the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP010683 thru ADP010703

INTEGRATING INFORMATION FROM MULTIPLE SOURCES: EXPERT DECISION MAKING PROCEDURES

Dr. Susan S. Kirschenbaum
Naval Undersea Warfare Center Division Newport
1176 Howell St.
Code 2211, Building 1171/1
Newport, RI 02841-1708
USA
kirschenbaumss@csd.npt.nuwc.navy.mil

Summary: Battlespace Management systems are often developed by decomposing the problem into separate functions. For example, the battle scene is decomposed into intelligence reports, sensor displays for each sensor, contact tracks for each sensor contact, environmental (weather, oceanography) conditions and predictions, sensor effectiveness predictions, geophysical / physical oceanographic pictures, etc. Once the problem has been decomposed and analyzed, the decision maker must put it back together in a mental information fusion process, integrating information. The tools to help the expert decision maker re-fuse the problem are far fewer and more difficult to develop than the tools to decompose. The research reported here takes an alternative approach by providing information displays that cluster and integrate information according to the expert decision maker's knowledge schema and procedural structure. A complex, time-dependant (but non-military) test domain with multiple, conflicting goals was selected. Functional partitioning required greater effort while procedurally based information-clustering resulted in more efficient (timely and accurate) decision making.

INTRODUCTION

The Problem: Battlespace Management systems are often developed by partitioning the problem into many functions or tasks. For example, one tool displays all the broadband noise, sensed in all directions. Another provides a similar display of narrowband noise received by each sensor. Another tool makes environmental (atmospheric or oceanographic) predictions for specific variables (wind / current speed, temperature profile, etc.). Yet another tool gives the current conditions. Several algorithms work to solve the target-motion-analysis problem. Thus each unit in the battlespace is decomposed into many separate signals and kinematic components, all independent from one another and from their underlying physical location and the constraints that it imposes. Decomposition facilitates efficient engineering of the algorithms and programs. Each function has its own set of developers, and therefore, its own set of tools. The consequence of this approach is that the problem is split into many different unassociated bits of information. However, the partitioning scheme is not necessarily congruent with the way that the decision maker solves the problems.

The task of the decision maker is to evaluate the available information, predict the effects of various action options, and communicate the decision. Evaluation includes integrating data from the different sources described above, comparing conditions to assumptions, assessing accuracy, etc. The available information is composed partially of the output of various tools and partially of unanalyzed or "raw" data. It includes history, current state, and predictions. It may contain considerable uncertainty and/or may change over time. Required decisions may include both what to do and when to act. Information management tools and decision aids are developed for these tasks because they are so complex and because the supporting information is so complex and uncertain. However, once the problem has been decomposed and analyzed, the decision maker must put it back together in a mental information-fusion process, integrating information from these many tools and phases. The tools to help the expert decision maker to put the problem back together are far fewer and more difficult to develop than the tools to take it apart.

A Proposed Solution: An alternative approach to decision aid development is to start with an understanding of the knowledge and procedures of the expert decision maker and then design tools to support these. With this knowledge, we could design information management decision aids in the way that new walkways are sometimes planned. That is, where natural paths occur because of repeated use by pedestrians, constructed (concrete, macadam, gravel, etc.) pathways are built. In the same way, battlespace management tools and decision aids should provide support for knowledge in the head -- the procedural paths we create through the task and the information.

Experts make use of the procedural components of their knowledge, as well as the declarative content: That is, they know *how-to* as well as *what, why, when,*

and *where*. Tools used to do a task and procedural knowledge of that task are not independent entities. The tool can facilitate the task procedures or, in the case of clumsy automation (Wiener, 1989), dictate conflicting procedures. The organization of information can provide the cognitive equivalent of affordances (Norman, 1988) or "handles" that facilitate performance or obstacles that hinder it. For example, calculators can use either arithmetic notation or "reverse Polish" notation. Arithmetic notation allows the user to enter numbers and operators as they would on paper (3 + 2 =) and supports the average user's procedural knowledge. Reverse notation requires the user to enter numbers first and then operators (3 2 + =). Although this notation groups like information (numerals, operators) together, it requires the average user to reorder the information from normal arithmetic procedures.

There is a well documented interaction between knowledge in the head and information in the world. Kleinmuntz and Schkade (1993) reviewed several studies that show how problem representation affects the speed and accuracy of identifying and assessing the situation, and consequently, the quality of the decisions made with that information. For example, Johnson, Payne and Bettman (1988) found that display format effects the likelihood of preference reversals (a well-documented decision error) in choice decision making. Decision makers in these studies shifted information gathering strategies as a function of display format. Brown and Klayman (1989) and Smith (1989) found that representation affects subjects' ability to identify key problem elements in naturalistic decision situations. Larkin (1989) has called this effect display-based problem solving because the availability and form of the information displayed can affect problem solving. For example, Russo (1977) found that a table of unit prices for an entire category of food facilitated price comparison and decision making as compared to unit prices displayed with each item, although unit prices are calculated by item, not category. One reason for this improvement may be the reduction in working memory load when appropriate information is clustered. Thus, the tools used to do a task and procedural knowledge of how to do that task are not independent entities. The tool can facilitate the task procedures or, in the case of clumsy automation (Wiener, 1989), dictate conflicting procedures.

To solve the problem posed above I propose providing information displays that cluster and integrate information according to the expert decision maker's knowledge schema and procedural structure rather than according to a functional one. I hypothesize that such a system would lead to more efficient decision performance. What I mean by efficient is equal or better performance in a shorter time, with less effort.

In the remainder of this chapter I will first report on an experiment that demonstrates the performance advantages for this idea and then I will discuss several military applications for the findings.

TESTING THE HYPOTHESIS

To test the hypothesis a complex, time-dependant (but non-military) test domain with multiple, conflicting goals was selected. The decision task was designed to have a one-to-one correspondence with key elements of the submarine problem. (One advantage of the non-military task was that many more experts were available. Additional evaluation verified the task validity.) Three information format schemes, alphabetical listing (format A), functional partitioning (format B), and procedurally based information-clustering (format C) were tested. Version C was designed by a bootstrapping procedure based on two individuals pilot testing versions A and B.

Three classes of dependent measures were used. The first was total time-on-task. The second reflected outcome performance, and the third measured processing activity. Results showed that version C lead to the most efficient performance. There was an interaction between performance measures and measures of processing time and processing effort. Functional partitioning required greater effort for limited performance improvement over the alphabetical format. Thus, the right organization scheme can provide the support for improved cognitive performance.

There are many possible partitioning schemes for categorizing and organizing information. Like the contents of a computer directory, tools on a workbench, or merchandise in a store, information in a decision support system can be organized by many attributes, including size, purpose, time, or order of use. The different organizational structures facilitate achieving different goals. Random placement speeds cleaning-up after a project, but organization by purpose speeds retrieval of tools from a workbench.

Phase 1: Information Organization: The experimental task was simulated, on-line, college course scheduling. This task has many elements in common with the target task, dynamic decision making under uncertainty, but has many more experienced individuals to serve as testers. To simulate an event-driven environment, classes could fill while the "student" was selecting a schedule. When a planned course was filled, the subject had to reassess the situation and find a new course that fulfilled the other requirements. Elements of data history were important because previous semester's records, program requirements, and course prerequisites had to be reconciled. A set of sometimes conflicting goals further

constrained choices (see Table 1). Lastly, of course, classes could not conflict with one another. To simulate the multiple sources of information, each function (e.g., instructor rating lists, course schedules, requirements lists, student history, course locations and distance maps, etc.) had its own information presentation. This task is not a simple scheduling problem because there is no single "optimal" or algorithmic schedule that solves all constraints and meets all the goals. It requires goal-driven decision making to achieve acceptable performance.

A scoring scheme was developed that operationalized each of these elements as values associated with accomplishing the goals and values for each of the choices (i.e., courses and instructors). It was predicted that scores would reflect the level of organization in the display schema.

Table 1: Goals, listed in priority order

- Register for 15-17 hours (5 courses).
- Try to fulfill requirements and prerequisites for both general education and your major. (Note that you may remain an industrial engineering major or select engineering psychology.)
- Try to schedule so that you have one full day or two half-days off. (One full day is preferable. Assume you have a job and will otherwise have to work on the weekend.)
- Try to get the best instructors possible. A list is provided of instructor ratings from a student survey.
- Try to avoid 8 am classes.

Apparatus Design Methods: Establishing the correct information structure can be an iterative, almost circular process as procedures can change when tools change. The question herein is not *how* to design displays, but what are the *effects* of information organization on performance. Three prototype information presentation schemes were developed. Versions A and B were modeled on the registration materials used by many pre-internet generations of students. These included student record; a catalogue listing general degree requirements and specific requirements for each major, course descriptions; prerequisites for each course; a schedule of courses for the upcoming semester; a student schedule sheet for recording selections; and an informal rating of faculty published in the student newspaper. Students had to determine the availability of seats for each course, by going to each department. For this experiment, this last step was consolidated into a single list. Selecting courses required multi-way comparisons among the sources of information, and across many pages in each.

Information in each of the sources was structured differently.

Although the majority of these materials were organized by academic department, other schemes were also used, including listings by time, by course number, and alphabetically, by name. Version A was intended to serve as a baseline of minimal performance and maximal task time. Armchair analysis suggested that organization alphabetical listings by course title and listing by course number was unlikely to match anyone's procedural or declarative knowledge schema for this kind of information. Thus, it was used for version A.

For Version B, recall and interview with individuals who had attended college prior to the computerization of registration led to organization by information type (student record, departmental course listing, requirements, etc.), much as it had been in my student days. To prevent the participants in Conditions A and B from reorganizing the information by opening multiple windows, the metaphor of an electronic book was used, with "pages" for each kind of information above. The book could only be open to one page at a time.
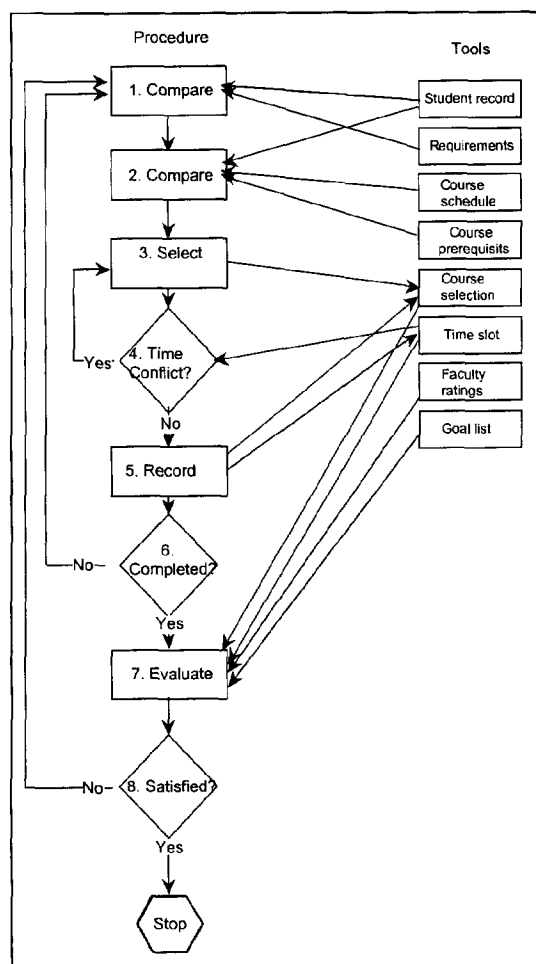
Figure 1: Steps used by a typical student to complete a course schedule.

Version C was modeled on modern computer registration. This was designed, not by attempting to recreate a historic artifact, but by a bootstrapping procedure based on two individuals pilot testing versions A and B. Figure 1 shows all of the steps used by these individuals[1]. The many steps used different subsets of the available information (see Figure 1). These subsets were used sequentially, as a single cluster, although the order was not invariant. For example, two clusters were used to make initial course selections. These were (1) requirements and student record of courses already taken, and (2) course prerequisites, student record, and times of potential courses.

The same information could be used by several steps. To accommodate all possible steps in this procedural approach to information organization, the clusters of information most often used by a single step were displayed in the same window or in other windows that

[1] Not all steps were used on every trial.

could be open simultaneously. Thus, only eye movements were necessary to obtain all the information used by any step.

PHASE 2 BEHAVIORAL EXPERIMENT

Participants: The two a priori requirements for participants were that they be recent college students with a minimum of eight semesters and that they had registered for college classes within the past five years. They could be considered experienced at the putative task. There were 10 women and 26 men evenly distributed across the three conditions. They had last registered for college courses an average of 2.86 years prior to the experiment. Educational level of the sample ranged from bachelors to doctorate degree. The experiment used a between subjects design with twelve participants per group.

Apparatus and materials: The task was a second year college registration. Participants were given goals, student records of course and grade history, prerequisites, a campus map with walking times, and instructor ratings. The task was timed and courses closed, dependent on the elapsed time. All experimental material was developed in Supercard and presented on a Macintosh computer with a 19 inch color display. Conditions A and B used a booklet-like format with only a single page visible at a time. The page numbers in the Table of Contents were hypertext links to the listed information. Categories are listed in Table 2.

Table 2: Categories of information in Table of Contents

- Goals
- Student record
- General requirements
- Departmental requirements for Major
- Course Prerequisites
- Courses Schedule
- Campus map
- Table of Instructor ratings
- Table of class size and seats remaining

In condition A, all information in the course schedule and prerequisites sections was listed in alphabetical order. Thus, Introduction to Psychology followed Introduction to Physics. As courses were not listed by course title (only course number) in the requirements and student record sections, this format required a search information retrieval strategy. In condition B course schedule and prerequisites were listed by department, and sequentially by number within department.

Condition C used the procedural format developed in Phase 1. It used a computer registration analogy with access to information via a menu. Multiple movable windows could be open simultaneously. These were scrollable and resizable when required (e.g., course schedule, registration card, and any other card with more than about 10 lines of information). As the screen and text were of the same size, approximately the same quantity of information was visible in all conditions.

In all three versions of the task, the program recorded windows opening, buttons being pushed, typed text, and the time (in ticks) associated with each interaction.

Procedure: The experiment took place in a small, sound-damped, experimental room. All instructions were presented on the computer screen. Participants were given introductory instruction on manipulation of the objects used in the program and on the task. There was a practice task for each condition that duplicated all of the screens, interactions, and information types. During the practice and before the actual experimental trial, participants were invited to ask questions, however, questions about strategy were not answered. No questions were answered after the experimental trial began. At the end of the experimental task, participants were asked to complete a computerized questionnaire and were debriefed. The questionnaire was designed to ascertain recall of relevant information, task strategy, computer and college registration expertise, and any comments about the experiment.

STATISTICAL RESULTS

Three classes of dependent measures were used. The first was total time-on-task (T). The second reflected outcome performance (P), and the third measured processing activity (A).

Performance was defined as the summation of the following four performance measures: the number of credits successfully registered (P_1), the sum of the requirements scores for all courses registered (P_2), the sum of the scheduling difficulty scores for all courses registered (P_3), and the average preference score for the instructors of all selected courses (P_4). Scheduling difficulty was computed as the number of seats in courses that would satisfy requirements times the number of credits, weighted by the scheduling priorities given in the goal list. Each of the four scores was determined a priori and was reflected in the goal set given to the participants.

The processing measures captured various aspects of the effort participants put into the task. These included, number of registration attempts (A_1), number of class close-outs (A_2), number of windows used (A_3), and number of times the subject iterated back and forth,

between any two windows (A_4). One full cycle from window a to b to a to b was counted as one iteration.

These measures were combined into an overall efficiency measure. Efficiency, E, was defined as the ratio of mean overall performance, $m_{(Pi)}$ to mean amount of processing, $m_{(Aj)}$, plus total time-on-task required to achieve that level of performance, T:

$$E = m_{(Pi)}/(m_{(Aj)} + T) \qquad (1)$$

The groups did not differ on any of the measures of computer experience or college registration experience. Table 3 shows means and standard deviations for all behavioral measures (T, P, A, & E). To facilitate comparisons among measures, all scores were transformed into standard scores with a mean of 50 and a standard deviation of 10.

Time-on-task: While means were not significantly different among groups, variances were large, time-on-task did contribute to individual performance differences. To account for differences in time taken by individual participants, performance and processing measures were computed per unit time. While not statistically different due to large variances, the trend was surprising. Versions A and C appeared equally fast (Figure 2).
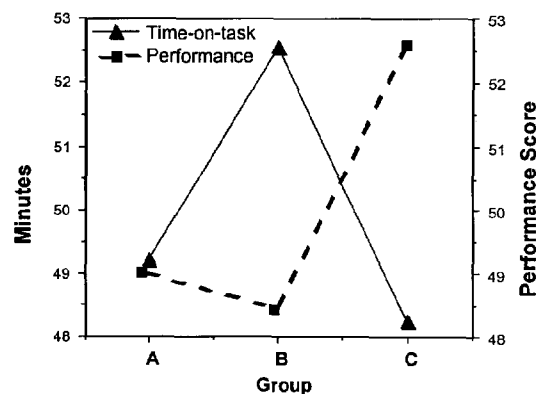

Figure 2: Mean time-on-task and mean performance.

Performance Measures: Overall performance, superimposed over time-on-task shows the relationship between the two. Those using version A found it so difficult that they basically gave up trying perform well. They just wanted to complete the task quickly. People using version B found that they could complete the task, but it took considerable time and effort.

Decomposing the performance measures provides the supporting detail necessary to understand this effect. The performance measures appeared to be composed of two compound measures that behaved very differently from one another (see Figure 3). The first,

$P_{1,2}$, was composed of the more concrete performance measures; P_1, the number of credits successfully registered and P_2, the sum of the requirement satisfaction scores for all registered courses. The tasks represented by these measures were essential for completion of the course schedule and did not reflect differences in performance. They replicated minimal or baseline performance. Although there appears to be a slight trend toward better performance for groups B and C, this was not significant, $F<1.0$.
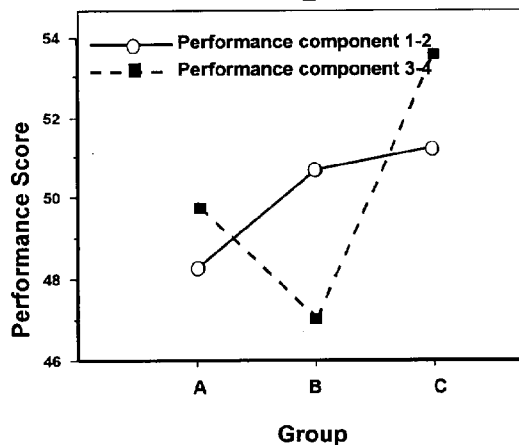

Figure 3: Mean performance on two compound measures for each display format.

Processing Measures: The process measures also showed two patterns of behavior (see Figure 4). For

Table 3: Means and standard deviations for all measures for all groups.

	Alphabetical		Functional		Procedural	
	M	SD	M	SD	M	SD
Time on						
task	49.24	9.76	52.54	10.62	48.21	9.94
Performance Measures						
P_1	48.40	11.77	50.97	6.36	50.60	11.62
P_2	48.33	12.20	50.17	8.87	51.52	9.23
P_3	49.65	10.07	47.69	11.35	52.59	8.73
P_4	49.67	11.46	46.61	8.60	53.82	9.29
Process Measures						
A_1	48.89	5.43	53.47	15.04	47.21	5.76
A_2	51.01	12.33	52.15	10.93	46.44	3.95
A_3	55.78	8.98	54.21	7.60	40.02	3.92
A_4	56.65	9.65	53.84	6.37	39.51	0.42
Efficiency Ratio						
	0.48	0.07	0.47	0.09	0.58	0.08

ease of analysis and discussion, these shall be called $A_{1,2}$ and $A_{3,4}$, with the understanding that the two components of each compound measure displayed the same pattern of results. The first compound measure was composed of measures A_1, registration attempts and A_2, number of close-outs. These are both indications of difficulties with the task, rather than the information format. There were no significant

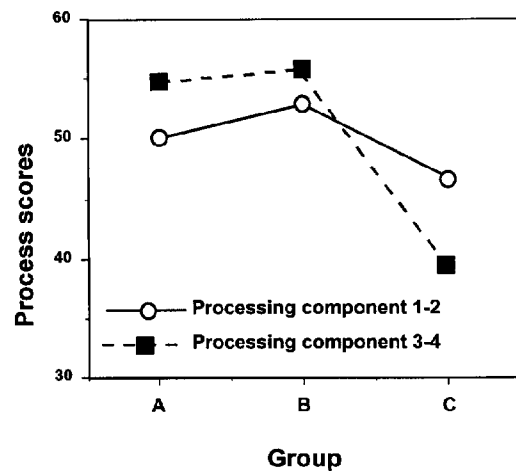differences among the conditions on this compound measure, $F(2,33) = 1.71$, n.s.

Group

Figure 4: Mean processing score on two compound measures for each display format.

The second compound performance measure, $P_{3,4}$, was composed of more difficult, evaluative and integrative tasks; P_3, the sum of the scheduling difficulty scores for all courses registered, and P_4, the average preference score for the instructors of all selected courses (see again Figure 3). These measures appeared to reflect an added effort to perform well, when possible. $P_{3,4}$ showed a paradoxical dip in performance with the functional display organization, B. This quadratic trend was marginally significant, $F(1,33)=4.07$, $p=.05$.

The second pair of processing measures; A_3, number of windows and A_4, number of iterations, are related to information accessibility and congruence with procedural needs. If the information format does not match the sequences used by procedural knowledge, the individual must collect it from where it is (indicated by A_3) and then create the sequence in working memory (encoding and sequencing indicated by A_4). There were significant differences among the groups on this pair of measures, $F(2,33) = 43.04$, $p<.001$. This was a very robust effect with $\eta^2 = 0.72$ and, in a post hoc test for trend, the quadratic trend was significant, $F(1,33) = 13.104$, $p<.005$.

Efficiency: The processing, performance and time-on-task measures combined to evaluate the effect of information organization of decision making efficiency. Participants who used the procedural information format were significantly more efficient in their decision making than were those using either of the other two formats, $F(2,33)=7.29$, $p<.005$ (see Figure 5). This was a robust effect, with $\eta^2 = 0.32$. In a post hoc test for trend, the quadratic trend was significant, $F(1,33) = 4.32$, $p<.05$.
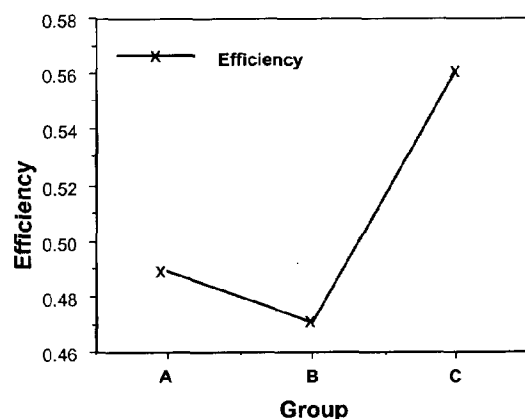
Figure 5: Efficiency (performance divided by processing effort and time) for each of the three display formats.

PROCEDURAL ANALYSIS

The first task of the procedural analysis was to evaluate the relationship between overall performance and overall procedural processes. This relationship can best be understood by examining Figure 6. As can be seen, there was an inverse relationship among these measures. Processing variables were moderately predictive of total performance score, $R^2 = 0.42$.
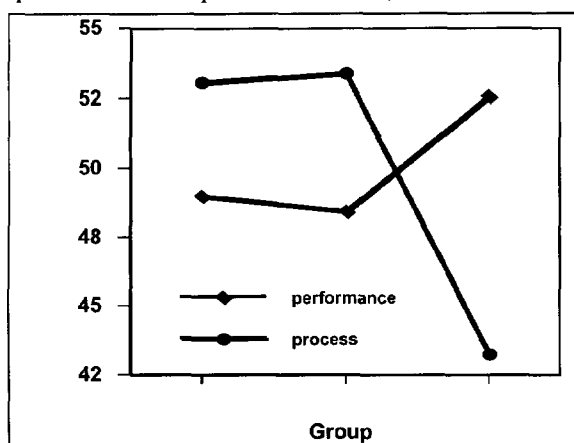

Figure 6: The relationship between performance and process measures for each format.

Iterations: The iteration measure is a reflection of the efficiency of procedures used by participants under each of the three conditions. In conditions A and B, participants physically iterated between pairs of information while in condition C they typically positioned information windows so that information used in the current step could be accessed with eye movements and did not require mouse actions. A typical pattern for the participants in condition A was to iterate between the schedule page and virtually every other page. However, there were numerous iterations among other pages. For participants in condition C, virtually all of the iterations were between the schedule page and one of the pages listing course

schedules. There were very few iterations for participants in condition C and these were different for each subject. Figure 7 shows typical patterns of iterations.
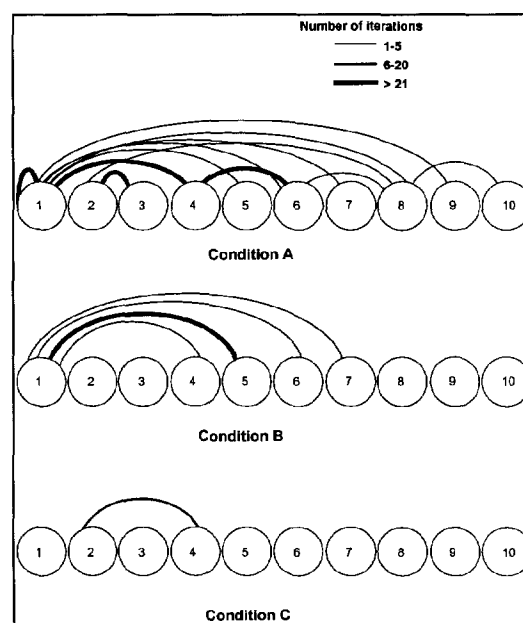

Figure 7: Typical patterns of iterations for participants in each of the three conditions. Node #1 is Table of Contents.

Sequences: Just as the number and pattern of iterations differed by condition, other aspects of performance differed by condition. Unfortunately, neither verbal protocols nor eye gaze data were collected so one can only infer goals. Self reports in the follow-up questionnaire shed no light on the question because there were no differences among groups and because participants often reported placing no weight on a source of information that they examined frequently or, conversely, placing heavy weight on information that they never accessed.

Sequences of pages (Conditions A and B) or windows (Condition C) provide insight into goals and validation of the procedure described in Figure 1. Several of the sequences were found in all conditions including those used for procedures 1 and 2. Only participants in Condition C were able to see a listing of courses by time slot. The majority of them used this display, but only for the last one or two course selections.

The sequence of the requirements listings either preceded or followed by student record (procedural step 1, Figure 1) is used to illustrate differences among the groups. Groups A and B examined requirements an average of 5.85 (SD = 1.29) and 6.75 (SD = 0.94) times, respectively while group C reviewed this important information an average of 10.75 (SD = 1.01) times. Moreover, review of this pair of windows was not evenly distributed across the duration of the task. It

appeared more frequently prior to early course selections. Apparently as the possibilities narrowed, many participants chose to skip step 1 in the procedure.

DISCUSSION

Providing guidance for the development of interfaces that support efficient (proficient and timely) decision making was a major motivator for this study. The most obvious conclusion is that these results indicate the importance of information organization that is congruent with procedural knowledge. Moreover, they show the impact of such organizational schemes on efficient performance. A more detailed examination of the data indicates that differences in support for procedural knowledge differentially change task procedures. Evidence for these differences are provided by all three sets of results reported here, performance score components, processing activity components, and the iterations picture.

Performance: Differences in the two compound performance scores, $P_{1,2}$, (the more concrete, required performance measures) and $P_{3,4}$, (the optional evaluative and integrative measures) suggest that motivation plays a subtle role in the equation. Performance on the $P_{1,2}$ measure was flat, but with large individual differences. A ceiling effect may have contributed to the lack of systematic differences.

$P_{3,4}$ performance was clearly affected by some aspect of the tool. As these measures related to qualitative performance, they might reflect the ease of use for the different organizational schemes. Clearly, Version C provided the cognitive affordances for better performance. The processing scores (see below) contribute to this conclusion.

Surprisingly, performance was not poorer on any measure for Condition A. Although that version of the task was intended to provide the *least* support for procedural knowledge, it did not differ from the traditional, department (like-with-like) organizational scheme. Might it be true that any information organization that is not congruent with procedural knowledge restricts performance?

Processing Activity: As with the performance compound measures, differences in the two compound processing measures showed different patterns. Compound measure $A_{1,2}$ reflects the task difficulty and, not surprisingly, did not differ among the three conditions. This lack of difference verifies that the task *could* be accomplished with any of the three versions.

Compound score $A_{3,4}$ measures physical interactions and reflects congruence between procedural knowledge and affordances in the tool. The systematic differences in $A_{3,4}$ indicate that the task was more easily and efficiently accomplished with version C. Again, there were no differences between versions A and B.

CONCLUSIONS AND IMPLICATIONS FOR BATTLESPACE MANAGEMENT SYSTEMS

We have seen that an information organization scheme based on procedural knowledge (Condition C) can facilitate performance at a complex, time-driven task. Moreover, performance without a reasoning-congruent information scheme hindered performance, regardless of the information organization. When the decision maker must expend both time and cognitive resources to compensate for the tool, those resources are not available to perform the task. Thus, the right organization scheme can provide the affordances for improved cognitive performance.

How would this work in a Battlespace Management System? As I am most familiar with submarine systems and with meteorological systems I'll use one of those, the submarine, as an example. The submarine systems include multiple sensor performance prediction algorithms, sonar sensors, target-motion-analysis algorithms, and battlespace displays. These tools correspond to the functions of search, detect, track, classify, localize, etc. However, when we examine the behavior of expert submariners, they do not limit themselves to this sequence (Gray, Kirschenbaum, & Ehret, 1997; Kirschenbaum, 1992). They iterate among the tools as they employ specific information gathering strategies. Thus a Battlespace Management System for submariners might, for example, facilitate comparing the output of a target-motion-analysis tool to the sonar traces at that bearing. Would the proposed course, speed, and range actually fall within the sonar trace, as displayed? How well would it match the region where the sonar could detect? We are currently building displays to answer these questions by showing these detection regions in 3-D, along with the possible tracks. Thus, we facilitate the very comparison procedures that we have observed submarine decision makers using.

The submarine 3-D display work is just beginning. The effects on performance have yet to be tested. The approach is much like that used in the experiment reported above. If the results replicate in this domain differences in affordances for procedural knowledge will again support differences in performance. While information systems have always been developed by analyzing perceived needs, a radically different suggestion is to design information management decision aids the way new walkways are sometimes planned. That is, where natural paths occur because of repeated use by pedestrians, constructed (concrete, macadam, gravel, etc.) pathways are built. These are not planned a priori, but develop from use. Only after the grass has been worn, are constructed paths built. In the same way, the information organization schemes should provide affordances for knowledge in the head -

- the procedural paths we create through the task and the information.

ACKNOWLEDGMENTS

REFERENCES

Chase, W. G., & Simon H. A. (1973). Perception in chess. *Cognitive Psychology, 4*, 55-81.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102(2)*, 211-245.

Gray, W. D., Kirschenbaum, S. S., & Ehret, B. D. (1997). The Précis of Project Nemo, Phase 1: Subgoaling and Subschemas for Submariners. In *Proceedings of the 1997 Conference of the Cognitive Science Society* (pp. 283-288). Hillsdale, NJ: Erlbaum.

Johnson, E. J., Payne, J. W. & Bettman, J. R. (1988). Information Displays and Preference Reversals. *Organizational Behavior and Human Decision Processes, 42*,1-21.

Kirschenbaum, S. S. (1992). Influence of experience on information-gathering strategies. *Journal of Applied Psychology*, 77, 343-352

Larkin, J. H. (1989). Display-based problem solving. In D. Klahr & K. Kotovsky (Eds.) *Complex information processing: The impact of Herbert A. Simon* (pp. 319-342). Hillsdale, NJ: Erlbaum.

Norman, D. A.. (1988). *The Psychology of everyday things.* New York: Basic Books.

Payne, J. W. (1982). Contingent Decision Behavior. *Psychological Bulletin, 92*, 382-402.

Russo, J. E. (1977). The value of unit price information. *Journal of Market Research, 14*, 193-201.

Smith, G.F.. (1989). Representational effects on the solving of an unstructured decision problem. *IEEE Transitions on Systems, Man, and Cybernetics, 19*, 1083-1090.

Wiener, E. L. (1989). Human factors of advanced technology ("Glass Cockpit") Transport Aircraft. Technical Report 117528, NASA.